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THERMOSPHERIC NEUTRAL WIND MEASUREMENT USING THE LWA1 AND THE AFRL DIGISONDE

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Final Report

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14. ABSTRACT

We use the first station of the Long Wavelength Array (LWA1) to observe low power echoes from meteors due to illumination of meteor trails from TV or VHF radar. We built and deployed 5 Data Recorder Storage Units (DRSUs) at LWA1 and use these to collect data from the LWA1. We have collected both LWA1 beam observations and Transient Buffer Narrowband (TBN) data which is an all-dipole mode. Both of these modes have extremely high data rates – up to 360 GB/hour in the case of TBN mode. This original objective was to characterize three-dimensional neutral wind patterns in 90-120 km altitude.

15. SUBJECT TERMS
Ionosphere; Thermospheric neutral winds; Meteor trails; Fireballs

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1. INTRODUCTION

This project made use of the first station of the Long Wavelength Array (LWA1) and the AFRL Digisonde located at Kirtland AFB, about 80 miles northeast of the LWA1 which is located on the Plains of San Agustin in central New Mexico. LWA1 is a compact array radio telescope operating in the 10-88 MHz band, co-located with the Very Large Array of the NRAO. LWA1 currently consists of 257 dual-polarization active dipole antennas in a 100 m x 110 m elliptical footprint with five outlier dipoles antenna located up to 500-m from the main array. Each dipole is individually digitized and then formed into 4 beams using a delay-and-sum technique. The beams can be pointed independently; thus LWA1 can be used similarly to 4 separate radio telescopes. The individual dipole signals can also be recorded. A subset of LWA1 science targets includes pulsars, astrophysical transients, the Sun, Jupiter, and the ionosphere, but innovative, technically feasible investigations of all kinds are welcomed.

Of particular interest to this work is the LWA's capability of performing real-time all-sky monitoring by sampling a narrow bandwidth from all 257 LWA1 dipoles (Transient Buffer Narrowband or TBN mode). The data stream is sent directly to a computing cluster located at the site which performs the cross-correlation and imaging in near real-time. Images of the sky from this analysis are made available on the web immediately and can be viewed on "LWA TV" at http://www.phys.unm.edu/ ~lwa/lwatv.html.

The goal of this project was to first detect meteors using the combination of the AFRL Digisonde and the LWA1 and then to use meteors to deduce properties of the neutral wind.

2. BACKGROUND

Meteor radar echos have long been used to determine neutral wind velocity in the ionosphere E region. As millions of meteors enter the Earths upper atmosphere every second, they collide with atmospheric molecules and cause the formation of a plasma trail as a dense plasma column that is carried away by neutral wind between 140 and 70 km. Small radars detecting specular meteor echoes in the direction perpendicular to the meteor path have been used for many years to deduce neutral wind velocity by measuring the average Doppler shift. Low power meteor radars require illumination of meteor trails from TV or VHF radar. This classical approach limits neutral wind measurement below 100 km altitude and at low ~1 km altitude resolution.

The LWA1 is capable of receiving both specular and non-specular echoes of digisonde radio waves transmitted from Kirtland AFB. The AFRL digsonde illuminates the sky over Kirtland and the LWA1 with low power 1-30 MHz radio waves. The LWA1 operates as a passive receiver using either the TBN mode or the beamforming mode (DRX). The frequency range of the LWA1 is 5-88 MHz.

3. METHODS and OBSERVATIONS

The AFRL digisonde is a low power Digisonde Portable Sounder capable of measuring high resolution temporal and spatial ionospheric electron density variations. Although it transmits only 300W of pulsed RF power, it compensates for its low power by digital pulse compression and coherent spectral (Doppler) integration, providing about 30dB of signal processing gain. During AFRL digisonde operations LWA1s coherent multiple receiver array can measure the frequency shift and phase difference on a number of antennas. See Figure 1 for a schematic of how the two instruments work in concert to detect meteors.

To support the observations we constructed 5 Data Recorder Storage Units (DRSUs). Each of these units consists of a 1U rack-mounted enclosure with an e-SATA controller board, and slots for 5 disk drives of 3 TB each. The disks are assembled into a RAID 0 array with a total of 15 TB recording capacity. The drives are Seagate SV35 model ST3000VX000 which have been designed for applications that require extended data transfers (such as video recording). An assembled enclosure is shown in Figure 1. Each DRSU can be mounted at the output of a beam or TBN and provides capacity for 40 beam-hours of recording, or for 30 hours of TBN recording.

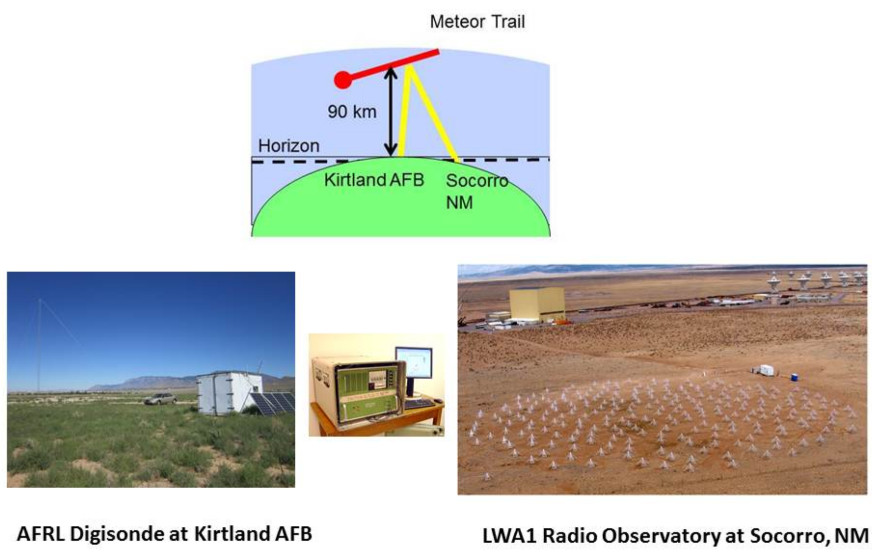

Figure 1. Schematic of LWA1 and Kirtland digisonde being used in conjunction.

Figure 2. The data recorder storage unit with the case open to expose the 5 drives.

The LWA1 observed 57 hours in project LL001 between December 8, 2012 and December 10, 2013. These observations were taken with a mix of TBN and DRX modes (see Table 1) at frequencies between 5 and 29 MHz. The raw data were collected on Data Recorder Storage Units (DRSUs) built specifically for this project. Following the observations, the data were off-loaded to external disk drives and delivered to AFRL for further analysis. UNM provided data readers and visualization tools in the LWA Software Library (LSL; Dowell et al. 2012).

Table 1. List of Observations

Session ID	Sub ID	Project	Target	UTC Date	Operator	Observations
1	1	LL001		12-08-12 00:00 UTC	CKG	1
1	2	LL001		12-11-05 11:00 UTC	JC	1
2	1	LL001		12-08-12 00:00 UTC	CKG	1
2	2	LL001		12-11-06 11:00 UTC	FS	1
3	0	LL001		12-11-07 11:00 UTC	FS	1
4	0	LL001		12-11-08 11:00 UTC	FS	1
5	0	LL001		12-11-17 10:10 UTC	FS	1
6	0	LL001		12-11-18 09:00 UTC	FS	1
10	0	LL001		12-12-13 11:00 UTC	SE	1
11	0	LL001		12-12-14 11:00 UTC	SE	1
12	0	LL001		12-12-22 11:00 UTC	JL	1
13	0	LL001		12-12-23 11:00 UTC	JL	1
17	0	LL001		13-02-04 20:30 UTC	JL	1
18	0	LL001		13-02-04 20:30 UTC	JL	1
19	0	LL001		13-02-04 20:30 UTC	JL	1
20	0	LL001		13-02-04 21:00 UTC	JL	1
21	0	LL001		13-02-04 21:00 UTC	JL	1
22	0	LL001		13-02-04 21:00 UTC	JL	1
23	0	LL001		13-02-04 21:00 UTC	JL	1
24	0	LL001		13-02-06 20:00 UTC	JL	1
25	0	LL001		13-02-06 20:00 UTC	JL	1
26	0	LL001		13-02-06 20:00 UTC	JL	1
27	0	LL001		13-02-06 20:00 UTC	JL	1
28	0	LL001		13-02-07 20:00 UTC	JL	1
29	0	LL001		13-02-07 20:00 UTC	JL	1
30	0	LL001		13-02-07 20:00 UTC	JL	1
31	0	LL001		13-02-07 20:00 UTC	JL	1
32	0	LL001		13-02-07 21:01 UTC	JL	1
33	0	LL001		13-02-07 21:01 UTC	JL	1
34	0	LL001		13-02-07 21:01 UTC	JL	1
35	0	LL001		13-02-07 21:01 UTC	JL	1
36	0	LL001		13-02-08 20:00 UTC	JL	1
37	0	LL001		13-02-08 20:00 UTC	JL	1
38	0	LL001		13-02-08 20:00 UTC	JL	1
39	0	LL001		13-02-08 20:00 UTC	JL	1
50	0	LL001		13-11-01 21:00 UTC	JR	2
51	0	LL001		13-11-01 20:55 UTC	JR	1
52	0	LL001		13-11-01 20:55 UTC	JR	1
53	0	LL001		13-11-01 20:55 UTC	JR	1
54	0	LL001		13-12-10 12:00 UTC	TE	1
55	0	LL001		13-12-10 14:00 UTC	TE	1
56	0	LL001		13-12-10 14:00 UTC	TE	1
57	0	LL001		13-12-10 14:00 UTC	TE	1
58	0	LL001		13-12-10 12:05 UTC	TE	1

Showing 1 to 44 of 44 entries

UNM students Caleb Grimes and Orlando Leone were supported in part by this award, along with UNM postdoctoral fellow Dr. Kevin Stovall. Orlando built the DRSUs used by this project and learned about the hardware we use on LWA1 to capture up to 1 Gbps. Caleb was primarily responsible for operating the station during the observations. In this way he gained valuable skills in learning how to control a telescope and gained valuable insights in what the Universe looks like at low frequencies. Dr. Stovall assisted the PI (G. Taylor) with the preparation of the observations and consulted on software development needed to pick out the meteor signals. Our collaborator, Dr. Joe Helmboldt, also consulted with us on the analysis of the observations.

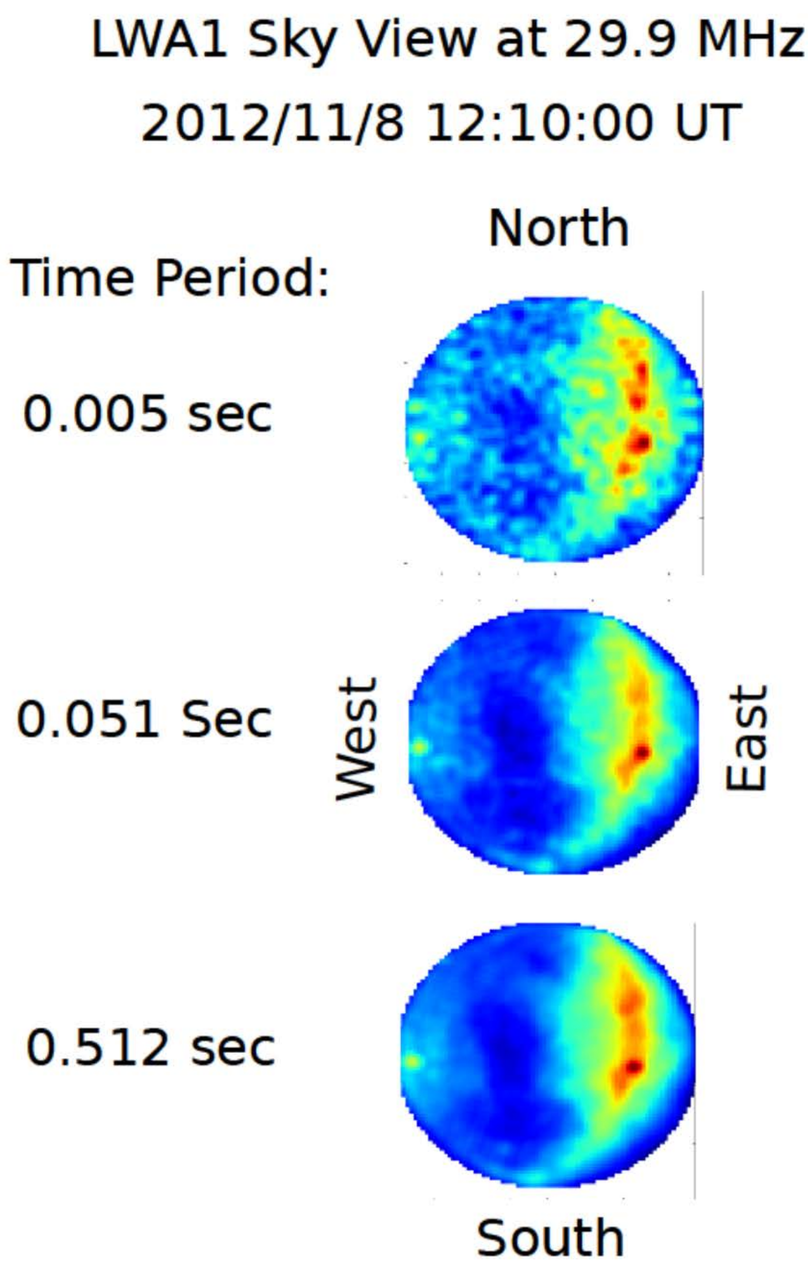

Figure 3. LWA 1 Sky view at three time resolutions during the Kirtland Digisonde operation.

4. RESULTS and DISCUSSION

From the TBN measurements we detected a number of meteor trails (see Fig.1). Further analysis is required in order to derive wind speeds and trail heights. Preliminary results were reported at a workshop on Space Weather held at UNM on October 2, 2013. Further analysis has been delayed by the retirement of one of our AFRL collaborators, Dr. Chin Lin, in late 2013. Some results are shown in Figures 4-9.

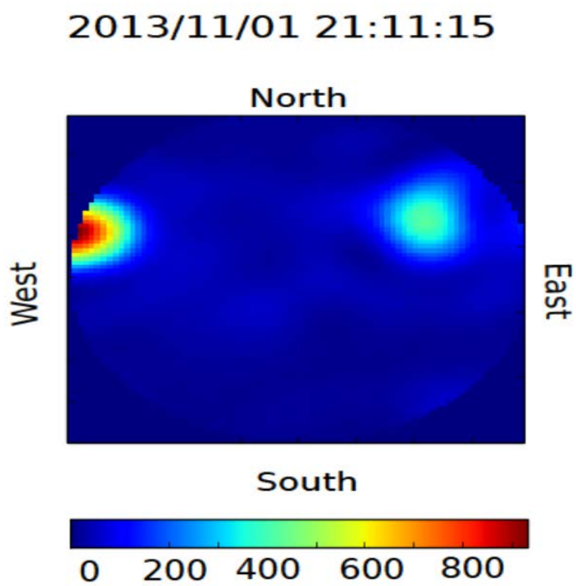

Figure 4. All-sky image detected by LWA1 at 9.1 MHz in the afternoon with a time period of 1 second. *The image shows digisonde reflection by the ionosphere as a bright spot in the upper right quadrant.*

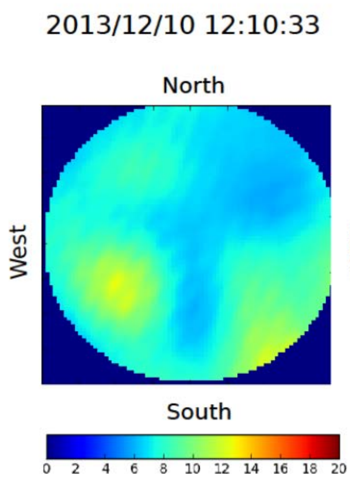

Figure 5. All-sky image detected by LWA1 at 5 MHz with a time resolution of 1 second.

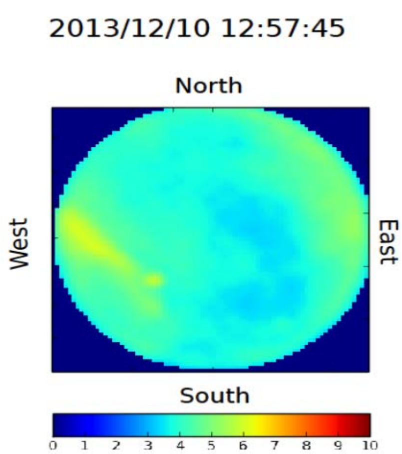

Figure 6. All-sky image detected by LWA1 at 29.9 MHz with a time resolution of 1 second.

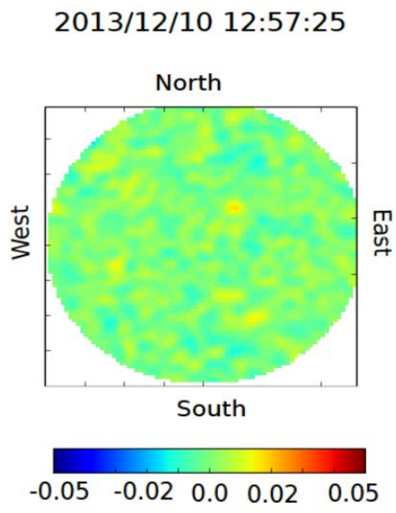

Figure 7. Example of the difference image between adjacent all-sky images showing bright spots. *The bright spot near the center of view in the upper right quadrant might be due to meteor reflection.*

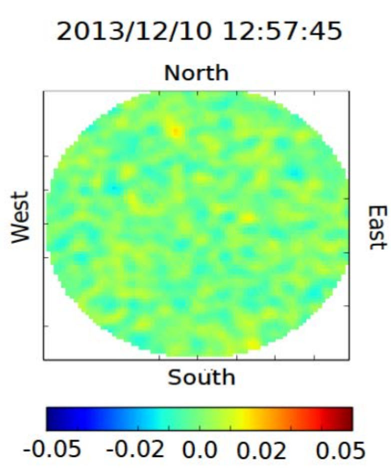

Figure 8. Another example of a possible meteor detection.

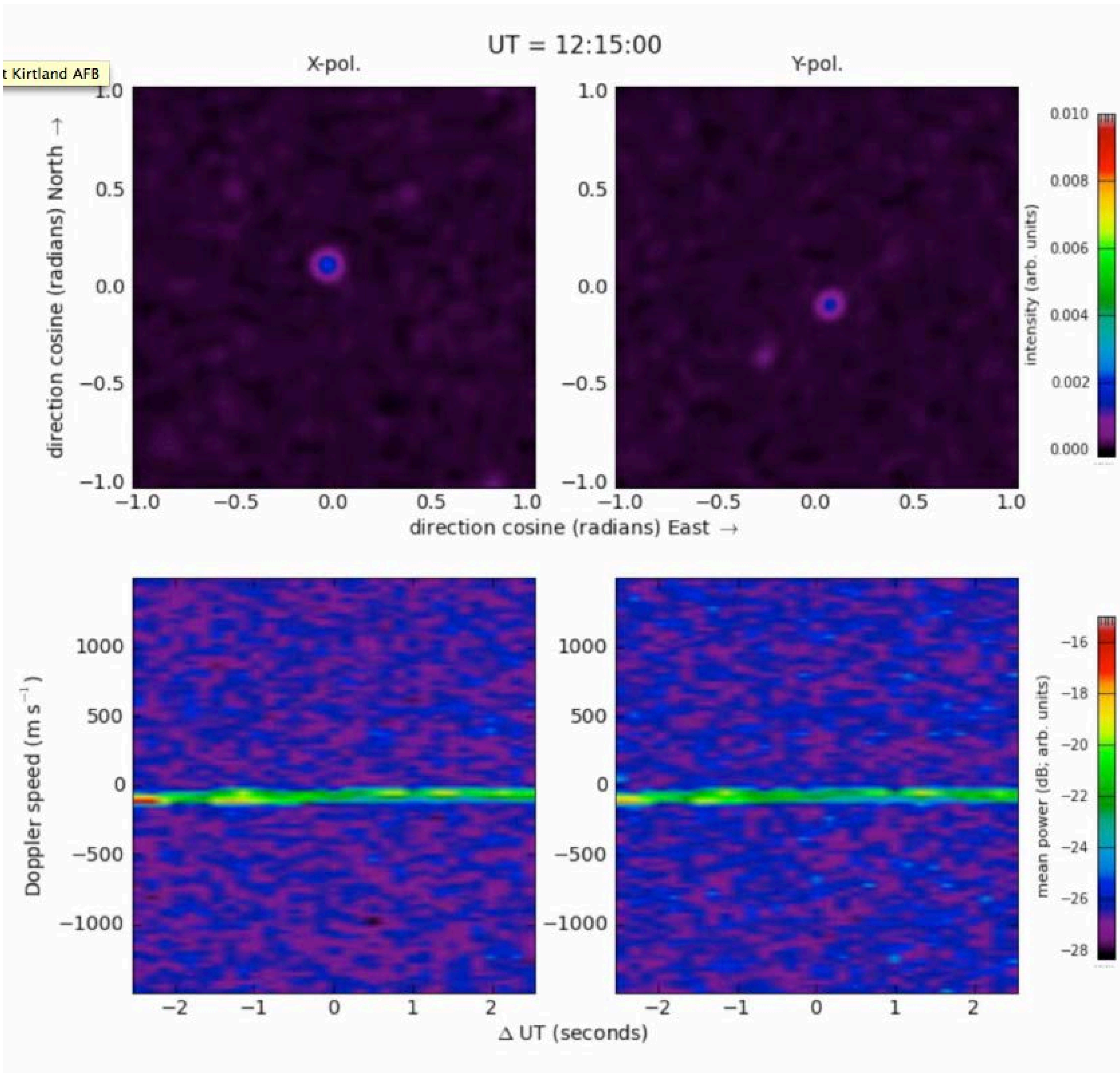

Figure 9. Detection of echoes from the Kirtland Digisonde off of meteor trails with LWA1.

In the course of this work on looking at reflections from meteors we discovered emission coming directly from the more energetic meteors, so-called “fireballs” (see Fig.10; Obenberger et al. 2014). While examining TBN observations at frequencies between 25 and 75 MHz, we found 49 long (10s of seconds) duration transients. Ten of these transients correlate both spatially and temporally with large meteors (fireballs), and their signatures suggest that fireballs emit a previously undiscovered low frequency, non-thermal pulse. This emission provides a new probe into the physics of meteors and identifies a new form of naturally occurring radio transient foreground. Below we summarize our arguments for why this must be emission from the fireball as opposed to reflection off of the ionized plasma.

First, typical transmitters are strongly polarized, resulting in reflections that are strongly polarized (Helmboldt et al. 2014; Close et al. 2011). However no significant amount of linear nor circular polarization has been detected from the observed transients. Secondly, a large portion of the RFI seen by LWA1 is narrower than the 75 kHz PASI band and is easily identifiable by its spectra (Obenberger and Dowell 2011). Yet none of the observed transients contain any spectral features. Thirdly, the light curves of the observed transients are consistent with each other, ranging from 30 to 150 s, showing a linear rise and a long exponential decay, and otherwise show a smooth evolution. A typical reflection from an overdense trail reaches maximum brightness in just a few seconds, maintains a relatively constant average brightness while undergoing sporadic dimming and re-brightening. It then quickly decays away once it expands to the point that the density reaches the under-dense criteria (Ceplecha et al. 1998; Helmboldt et al. 2014). The observed transients are also inconsistent with light curves from non-specular echoes, which vary greatly from one to the next, following no particular pattern. More importantly, however, non-specular echoes are weaker and more rare than over-dense specular echoes (Bourdillon et al. 2005; Close et al. 2011). Therefore if the LWA1 were seeing non-specular reflections it should also see many more bright specular reflections scattering from the same transmitters. Finally, the observed transients have azimuths and elevations consistent with the uniform distribution convolved with the LWA1 power pattern. This distribution implies that the sources appear in random locations with no preferable sky position. This is inconsistent with what is expected from specular echoes of man-made radio frequency interference (RFI), which should increase towards the horizon due to the increased number of incident angles with distant transmitters required for forward scattering. The observed pattern could be consistent with nearby transmitters. However, because the signal strength depends on the inverse-cube of the distance to the meteor, there should be many very bright nearby RFI sources on the horizon but these are not observed. This pattern is also inconsistent with non-specular reflections, which are preferentially located in a relatively small region of the sky that satisfies the requirement that the pointing vector is perpendicular to the geomagnetic field (Bourdillon et al. 2005; Close et al. 2011). For these reasons it seems unlikely that forward scattering is responsible for the signals detected from fireballs. It is therefore our conclusion that fireball trails radiate at low frequencies.

Decametric radio emission from meteors has not been previously detected, but this is not the first time its existence has been discussed. Hawkins (1958) conducted a search for radio emission, but reported only upper limits with a 5 sigma sensitivity of 10^8 Jy at 30 MHz for 1 s bursts. It is also interesting to note that in the last several decades detections of extremely low frequency (ELF) and very low frequency (VLF) emission have been reported coincident with large meteors (Guha et al. 2012; Keay 1980). The physical mechanism responsible for this emission is not well understood, but might be related to our detections of higher frequency emission.

Given the vast range in energies and size scales of meteors and their corresponding plasma trails, this emission may exist at a wide range of frequencies, timescales, and energies. Investigating this emission further will yield new insights into the physics of meteors and their interaction with our atmosphere.

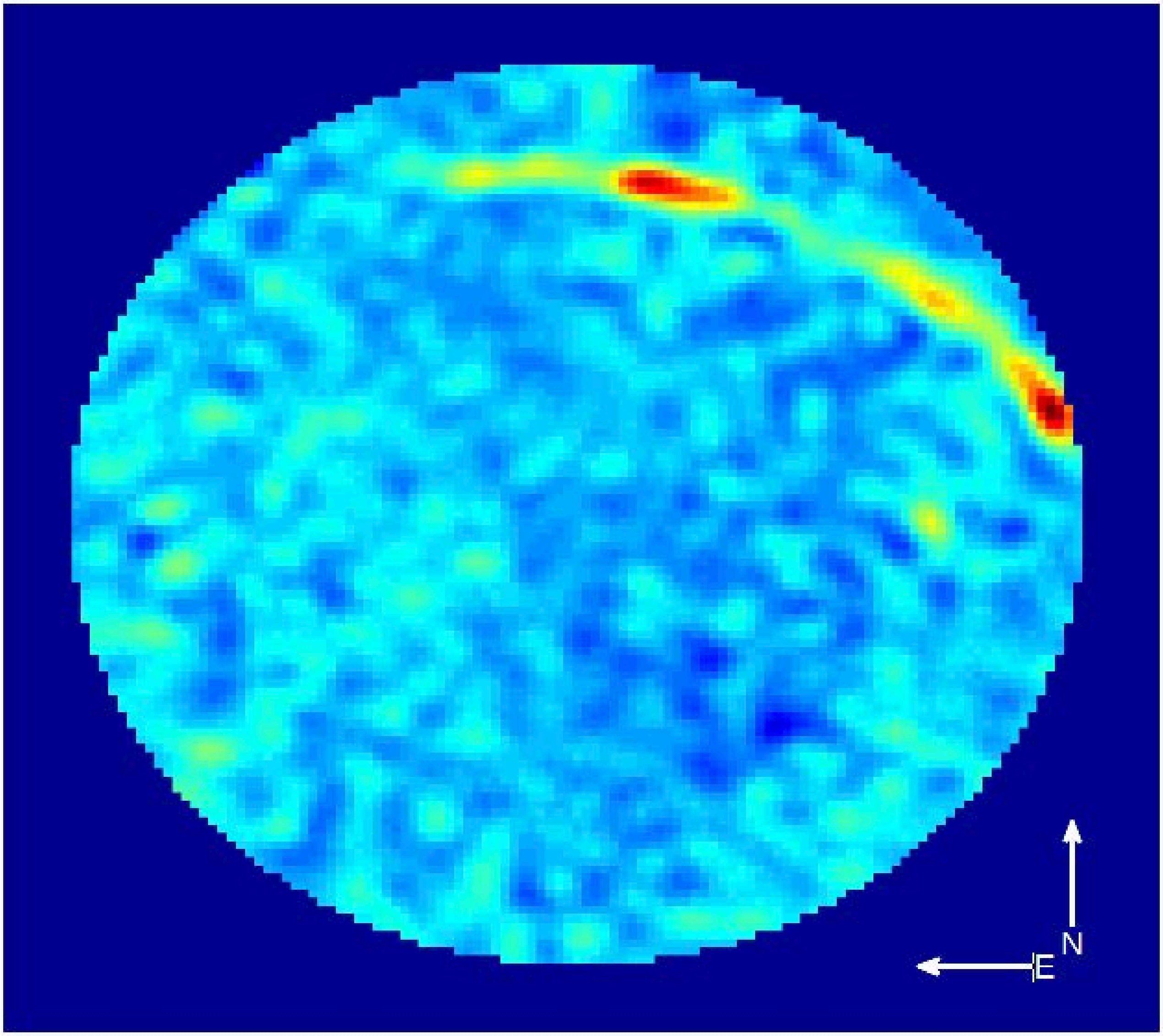

Figure 10. Image of the sky, after subtraction, of the fireball of January 21, 2014 which covered 92◦. *The edge of the circle marks a cutoff of 25◦ above the horizon.*

Moreover fireballs are now a known radio transient foreground source and need to be taken into account when searching for cosmic transients. It is interesting to note that transient atmospheric phenomena, unknown to emit at radio frequencies, have been proposed as the possible source of Perytons and perhaps even Fast Radio Bursts (Burke-Spoloar et al. 2011).

5. CONCLUSIONS

Due to the low transmitted power we have only been able to detect meteor reflections at 29 MHz with the LWA1 from the AFRL Digisonde. Observations at 5 and 9 MHz produce reflections off of the ionosphere but have not yielded detections of meteors. This is likely due to a combination of improved sensitivity and reduced interference at the higher frequency. Some of the same tools used to detect meteor trails using the Kirtland digisonde have also been applied to the case of using "transmitters of opportunity" in order to detect meteors with the LWA1. Specifically we have demonstrated that using TV Channel 2 transmitters at 55.25 MHz it is possible to detect over 10,000 meteors/hour (Helmboldt, J. F. et al., 2014, Radio Science, 49, 3). We have also detected intrinsic low frequency emissions from bright meteors.

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